Chapter 7
Levees and Floodwalls

7-1. Overview

This chapter describes the impact of and hydrologic engineering requirements for planning levees and floodwalls. It also describes interior-area facilities and the requirements for planning those. A checklist of the requirements for formulating and properly evaluating plans is presented as Table 7-1. Because of their unique layout, sizing, and design requirements, a separate checklist is provided for interior areas as Table 7-2.

7-2. Applicability

Levees and floodwalls are effective damage-reduction measures in the following circumstances:

a. Damageable property is clustered geographically.

b. A high degree of protection, with little residual damage, is desired.

c. A variety of property, including infrastructure, structures, contents, and agricultural property, is to be protected.

Table 7-1
Checklist for Levees and Floodwalls

Hydrologic Engineering Study Components	✓	Issues
Layout		Minimize contributing interior runoff areas (flank levees, diversions, collector system)
		Minimize area protected to reduce potential future development per Executive Order 11988
		Investigate levee setback versus height tradeoffs
		Determine right-of-way available for levee/wall alignment
		Minimize openings requiring closure during flood events
Economics		Determine with-project modifications to stage-discharge function for all existing and future conditions
		Quantify uncertainty in stage-damage function
		Formulate and evaluate range of levee and interior area configurations for various capacities using risk-based analysis procedures
		Determine expected capacity/stage exceedance probability
Performance		Determine expected annual exceedance probability
		Determine expected lifetime exceedance probability
		Describe operation for range of events and sensitivity analysis of critical assumptions
		Describe consequences of capacity exceedances
		Determine event performance
		Formulate OMRR&R plan and prepare O&M manual to include surveillance and flood fighting
Design		Design for levee/floodwall superiority at critical features (such as pump stations, high-risk damage centers)
		Design overtopping locations at downstream end, remote from major damage centers
		Provide levee height increments to accommodate settlement, wave run-up
		Design levee exterior erosion protection
		Develop flood warning/preparedness plan for events that exceed capacity
Environmental and Social		Evaluate aquatic and riparian habitat impact and identify enhancement opportunities
		Anticipate and identify incidental recreation opportunities

Table 7-2
Checklist for Interior Areas

Hydrologic Engineering Study Components	✓	Issues
Layout		Define hydraulic characteristics of interior system (storm/drainage system, outlets, ponding areas, etc.)
		Delineate environmentally sensitive aquatic and riparian habitat
		Identify damage centers, delineate developed areas, define land uses for site selection
Economics		Determine with-project modifications to interior stage-frequency function for all conditions
		Quantify uncertainty in frequency function
		Formulate and evaluate range of pond, pump, outlet configurations for various capacities using risk-based analysis procedures
Performance		Determine expected annual exceedance probability
		Determine expected lifetime exceedance probability
		Determine operation for range of events and sensitivity analysis of critical assumptions
		Describe consequences of capacity exceedances
		Determine event performance
		Formulate OMRR&R plan and prepare O&M manual to include surveillance and flood fighting
Design		Formulate/evaluate preliminary inlet/outlet configurations for facilities
		Formulate preliminary operation plans

d. Sufficient real estate is available for levee construction at reasonable economic, environmental, and social costs.

e. The economic value of damageable property protected will justify the cost of constructing the new or enhanced levee and floodwalls.

7-3. Levee and Floodwall Overview

A levee is "... an [earthen] embankment whose primary purpose is to furnish flood protection from seasonal high water and which is therefore subject to water loading for periods of only a few days or weeks a year" (EM 1110-2-1913). Figure 7-1 shows a cross section of a simple levee. A floodwall serves the same purpose under similar circumstances, differing only in the method of construction. It is subject to hydraulic loading on the one side which is resisted by little or no earth loading on the other side. Figure 7-2 shows a variety of floodwalls.

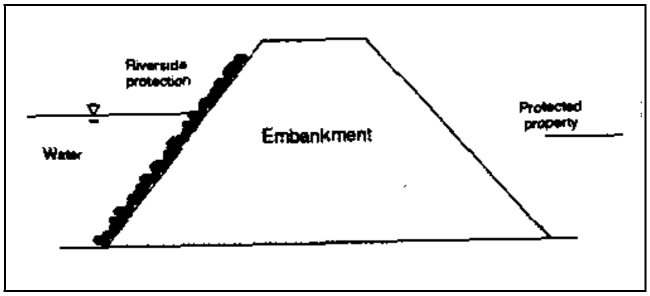

Figure 7-1. Cross section of simple levee

7-4. Flood Damage Reduction Assessment

a. Levees and floodwalls (hereafter referred to as levees for brevity) reduce damage by reducing flood stage in the protected area. They do so by blocking overflow from the channel onto the floodplain. This is represented by a modification to the stage-damage function, as shown in Figure 7-3. S_1 represents the minimum stage, without the levee, at which damage is incurred. The curve represents the remainder of this without-levee function. With the levee in place, the stage at which damage is initially incurred rises to an elevation equal to the height of the levee. This is designated S_2 in the figure. If the water stage rises above this, the levee is overtopped. Then the damage incurred, designated S_2 in the figure, will equal or exceed the without-levee damage.

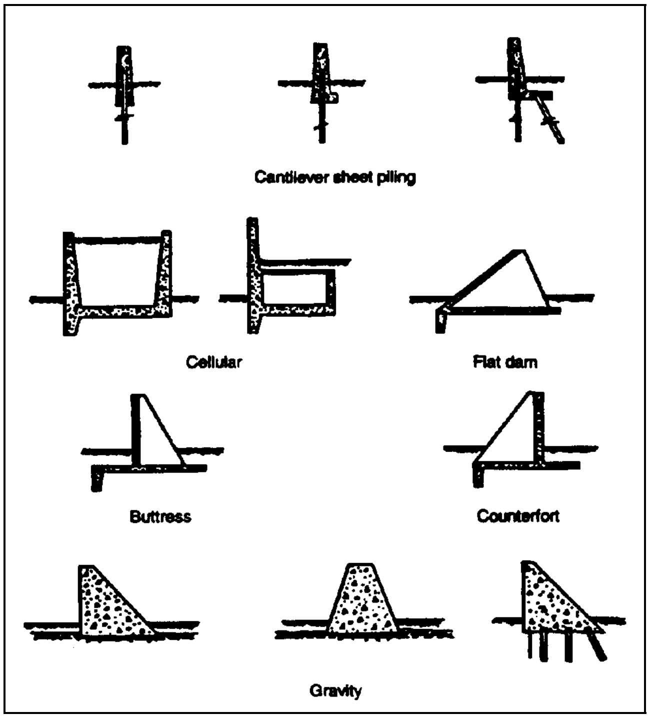

Figure 7-2. Floodwall types. In all cases, water to left, protected area to right

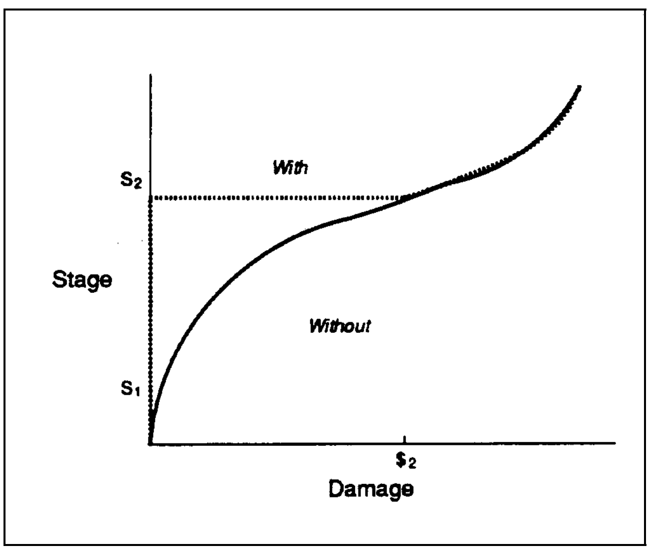

Figure 7-3. Stage-damage function modification due to levee/floodwall

b. A levee may also modify the discharge-frequency function and the stage-discharge relationship. The levee restricts flow onto the floodplain, thus eliminating the natural storage provided by the floodplain. This may increase the peak discharge downstream of the levee for large events that would flow onto the floodplain without the levee. Further, as the natural channel is narrowed by the levee, the velocity may increase. This too may increase the peak discharge for larger events. Modifications to the discharge-frequency function due to a levee are identified with the river hydraulics models or with routing models described in EM 1110-2-1417 and EM 1110-2-1416. These model the impact of storage on the discharge hydrograph and will reflect the loss of this storage. Historical or hypothetical runoff hydrographs can be routed with the selected model to determine discharge peaks with the proposed levee. For example, the modified Puls routing model described in EM 1110-2-1417 uses a relationship of channel discharge to channel storage with the continuity equation to determine the channel outflow hydrograph. A levee will reduce storage for discharge magnitudes that exceed the channel capacity, so the impact will be reflected.

c. Introduction of a levee alters the effective channel cross section, so the levee alters the stage-discharge relationship. The impact of this change can be determined with the river hydraulics models described in EM 1110-2-1416. As with channel alteration, the impact of a levee can be determined by modifying the parameters which describe the channel dimensions. Repeated application of the model with various discharge magnitudes yields the stage-discharge rating function for a specified levee configuration.

7-5. Interior-Area Protection

Figure 7-4 shows an area protected from riverine flooding by a levee. Such a levee (or floodwall) is referred to commonly as the line-of-protection. In this case, the line-of-protection is constructed so natural high ground integrates with the levee to provide the protection; elevation contours shown in the figure illustrate this. The elevation contours also illustrate a problem. The line-of-protection excludes floodwater, but it also blocks the natural flow path of runoff to the river. The protected area, which was formerly flooded by the slow-rising river is now flooded by local runoff, with little warning. This flooding may be only nuisance flooding, or in some cases, it may be flooding that is as dangerous or more dangerous than the riverine flooding. EM 1110-2-1413 describes requirements for interior studies.

a. *Solutions to interior flooding problem.* To accommodate local runoff, some or all of the facilities shown in Figure 7-5 may be provided. The interior-area runoff is passed through the line-of-protection by a gravity outlet when the interior water level is greater than the

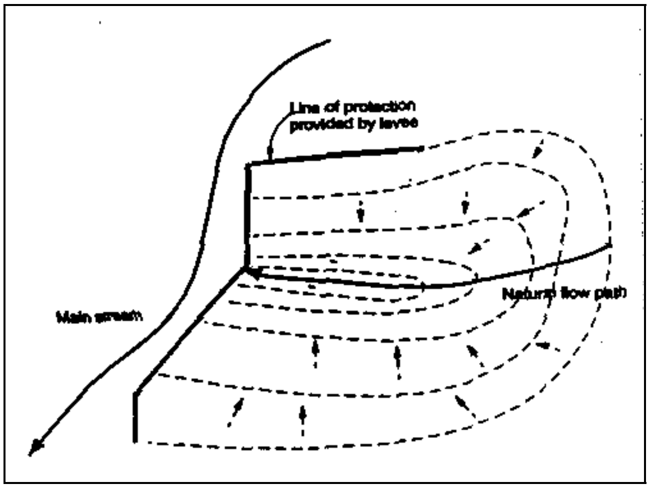

Figure 7-4. Plan view of levee with interior area

exterior level. This outlet may have a gate valve and a flap gate that close to prevent flow from the river into the interior area during high stage. When the exterior stage exceeds the interior stage, interior floodwater is stored in the interior pond and pumped over or through the line-of-protection. This is referred to as a blocked gravity condition.

b. Minimum facility.

(1) Some portion of the interior-area components must be included as a part of any levee plan proposed; these are designated the "minimum interior facility." (See EM 1110-2-1413.) This minimum facility should provide flood protection such that during gravity condition, the local storm-conveyance system functions essentially as it did without the line-of-protection in place, for floods less than the storm-sewer design event. Consequently, the minimum facility often will consist of natural storage and gravity outlets sized to meet local drainage design criteria. If no local storm-sewer system exists, but one is planned, the anticipated design criteria are used for planning the minimum facility.

(2) The minimum facility is intended to be the starting point for planning interior-area protection. According to EM 1110-2-1413, "It is expected that the interior facilities included in the final plan will provide interior area flood relief for residual flooding." However, the incremental benefit of any additional facilities must exceed the incremental cost. This requirement and analysis procedures are described in detail in EM 1110-2-1413.

c. Analysis.

(1) Hydrologic analysis of interior area behavior is complex because of the interaction of the interior and exterior waters. EM 1110-2-1413 describes three interior-area analysis methods. These are summarized in Table 7-3. The analysis approach chosen is based on available resources, available data, and technical knowledge. The decision should be made when the HEMP is

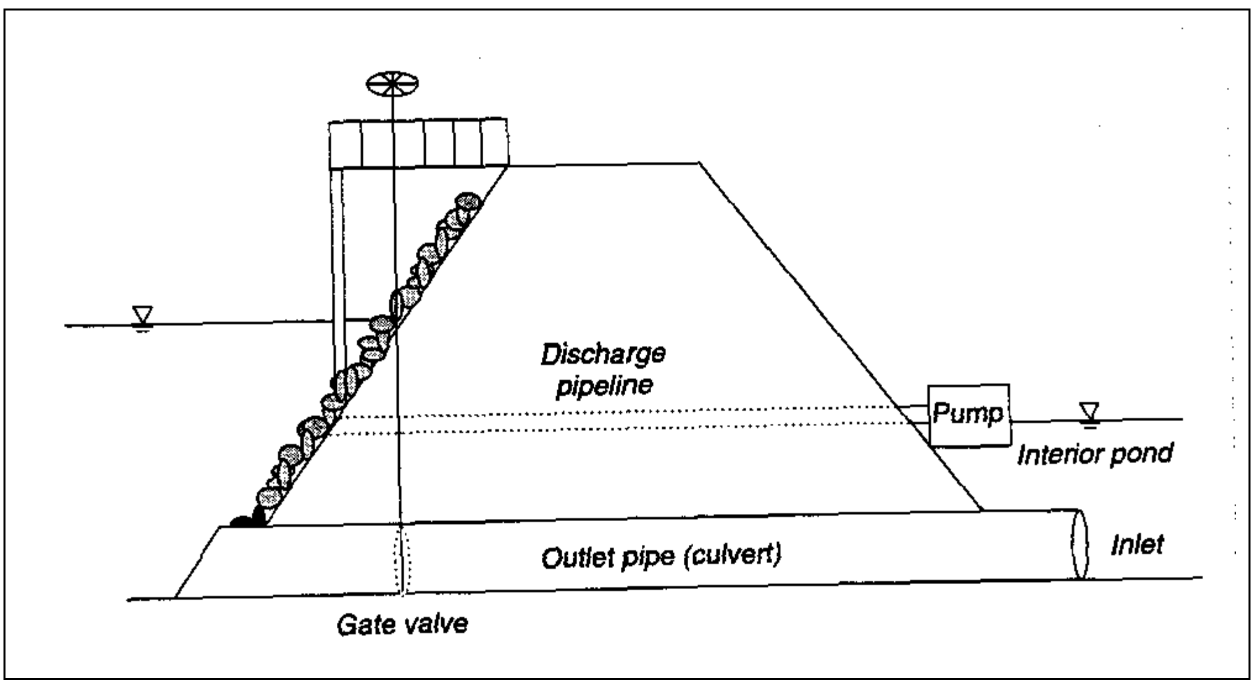

Figure 7-5. Components of interior-area protection system

Table 7-3
Interior-Area Analysis Alternative (from EM 1110-2-1413)

Method	Summary
Continuous record simulation	Simulate without-project and with-project conditions with continuous records of exterior and interior hydrology. These records may be historical flows or flows defined with "streamflow generation" techniques. Use runoff-routing models with recorded rainfall if necessary to estimate discharge. Simulate pond, outlet, pump operation for period. Develop necessary stage-frequency functions, duration estimates for economic analysis.
Discrete historical or hypothetical event simulation	Develop stage-frequency function for exterior with event simulation flood events that have an effect on interior flooding when interior flooding occurs coincidentally. Simulate without-plan and with-plan conditions for interior area with discrete historical or hypothetical events for low exterior stages that do not affect interior flooding. Develop interior stage-frequency function. Combine the two stage-frequency functions using the joint-probability theorem.
Coincident frequency analysis	For situations in which occurrence of exterior and interior flooding is independent, apply total probability theorem to define stage-frequency functions. To do so, develop exterior stage-frequency function, simulate system performance to develop interior frequency function for various exterior stages, combine functions.

developed. (See paragraph 1-7 of this manual for a description of the HEMP.)

(2) The HEC-IFH computer program (USACE 1992b), which is described in Appendix B, is specifically designed for the simulation required for interior-area analysis.

7-6. Design Exceedance

a. The principal causes of levee failure are (1) internal erosion, known as piping; (2) slides within the levee embankment or the foundation soils; (3) overtopping; and (4) surface erosion. The hydrologic engineering study must integrate geotechnical engineering elements to guard against failures due to piping and slides; flow nets may be required to provide sufficient information for proper design.

b. The likely locations and impact of levee overtopping must be addressed. This is a particularly difficult task, because the hydraulics problem created by levee overtopping is a multi-dimensional, unsteady flow problem. Further, when a levee is overtopped, it may breach, so complete analysis also includes the components of a dam-failure analysis. Nevertheless, information on the impact of the failure, including estimates of extent of the inundated area, warning time, and property and lives at risk must be determined. An unsteady fluvial-process model may provide information necessary for this analysis.

c. Surface erosion cannot be eliminated completely, but if proper precautions are taken, the likelihood of levee failure due to this can be minimized. EM 1110-2-1913 offers specific guidance in protecting riverside slopes; Table 7-4 summarizes this guidance.

7-7. Other Technical Considerations

Most levee projects and some interior-area protection schemes are designed to operate automatically and only require surveillance of operation during floods. A complete plan will include provisions for this surveillance and for flood-fighting activities, which involve special precautions to ensure the safety and integrity of levees. EM 1110-2-3600 notes that "It is important that managers of water control systems be properly appraised of the status of levee projects in conjunction with the overall control of a water resource system." This will ensure that gates are opened or closed properly, pumps are turned on or off as necessary, and access openings in the levee or floodwall are closed properly in anticipation of rising floodwater.

Table 7-4
Methods of Protecting Levee Riverside Slopes (from EM 1110-2-1913)

1. If duration of flooding is brief, provide grass protection, unless currents or waves act against levee.

2. Provide additional protection if embankment materials are fine-grained soils of low plasticity (or silts), as these are most erodible.

3. If severe wave attack and currents are expected, shield riverside slope timber stands and wide space between riverbank and levee.

4. Take care to accommodate scour due to flow constrictions and turbulence caused by bridge abutments and piers, gate structures, ramps, and drainage outlets.

5. To minimize turbulence and susceptibility to scour, avoid short-radius bends and provide smooth transitions where levees meet high ground or structures.

6. Depending on degree of protection needed and relative costs, provide slope protection with grass cover, gravel, sand-asphalt paving, concrete paving, articulated concrete mat, or riprap.